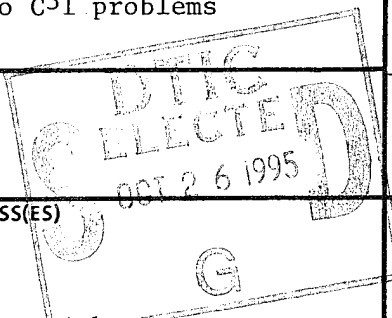


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DISCRETE EVENT DYNAMIC SYSTEMS MODELLING AND  
OPTIMIZATION  
WITH APPLICATIONS TO C<sup>3</sup>I PROBLEMS

FINAL REPORT

AUGUST 20, 1995

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4. BODY OF REPORT

#### A. STATEMENT OF THE PROBLEM STUDIED

It has been more than 10 years now since the concept of Discrete Event Dynamical Systems (DEDS) was first introduced into the system research society. The development of the theory and practice in the past decade have been tremendous and the interests from both academic and industry are ever increasing. The motivation of introducing such a concept was the observation that, due to the sweeping applications of digital computers, and the increasing complexity of our man-made world, the management of event-driven dynamic systems will inevitably become the major demand and challenge to system engineers. In the civilian engineering practice we have already been attacking the modeling, performance analysis, management and control of event-driven dynamic systems such as computer/communication networks, flexible manufacturing systems, air traffic control systems, inventory systems, etc. The common feature of these systems is that their dynamic evolution in time are event-driven, asynchronous, mostly governed by man-made rules. The "state" of these systems changes only at discrete, possibly random, instants of time. In contrast to the continuous variable dynamical systems (CVDS) that has been traditionally the center of the the systems research, these are systems that can not be described by difference or differential equations. It is clear that the military C<sup>3</sup>I/logistic systems belongs to the discrete event dynamical systems category. In this research project our effort is to tackle difficult performance optimization and analysis problems as well as the modeling issues for combat simulation models.

#### B. SUMMARY OF THE MOST IMPORTANT RESULTS

In this research project we have developed a general optimization approach, the Ordinal Optimization approach, for DEDS performance optimization. We also developed a rational approximation approach to performance analysis for many computer and communication systems. We worked with the U.S. Army Concept Analysis Agency to develop methods for preserving the stochastic fidelity in hierarchical battle simulation models.

##### 1. Ordinal Optimization:

It can be argued that **OPTIMIZATION** in the general sense of making things **BETTER** is the principal driver behind all of prescriptive scientific and engineering endeavor, be it operations research, control theory, and engineering design. It is also true that the real world is full of complex decision and optimization problems that we cannot solve. While the literature on optimization and decision making is huge, much of the concrete analytical results are associated with what may be called **Real Variable Based methods**. The idea of successive approximation to an optimum (say, minimum) by sequential improvements based on local information is often captured by the metaphor of "skiing downhill in a fog". The concepts of gradient (slope), curvature (valley), and trajectories of steepest descent (fall line) all require the notion of derivatives and are based on the existence of a more or

less smooth response surface. There exist various first and second order algorithms of feasible directions for the iterative determination of the optimum (minimum) of an arbitrary multi-dimensional response or performance surface. Considerable number of major success stories exist in this genre including the Nobel prize winning work on linear programming. It is not necessary to repeat or even reference these here.

On the other hand, we submit that the reason many real world optimization problems remains unsolved is partly due to the changing nature of the problem domain in recent years which makes calculus or real variable based method less applicable. For example, large number of human-made system problems, such as manufacturing automation, communication networks, computer performances, and/or general resource allocation problems, involve combinatorics rather than real analysis, symbols rather than variables, discrete instead of continuous choices, and synthesizing a configuration rather than proportioning the design parameters. Such problems are often characterized by the lack of structure, presence of large uncertainties, and enormously large search space. Optimization for such problem seem to call for general search of the performance terrain or response surface as opposed to the "skiing downhill in a fog" metaphor of real variable based performance optimization<sup>2</sup>. Arguments for change can also be made on the technological front. Sequential algorithms were often dictated as a result of the limited memory and centralized control of earlier generations of computers. With the advent of modern general purpose parallel computing and essentially unlimited size of virtual memory, distributed and parallel procedures or a network of machines can work hand-in-glove with **Search Based method** of performance evaluation. It is the thesis of this research to argue for such a complementary approach to optimization.

If we accept the need for search based method as complement to the more established real variable based analytical techniques, then we can next argue that to quickly narrow the search for optimum performance to a "good enough" subset in the design universe is more important than to estimate accurately the values of the system performance during the initial stages of the process of optimization. We should compare order first and estimate value second, i.e., **ordinal optimization** comes before **cardinal optimization**. Colloquial expressions, such as "ballpark estimate", "80/20 solution" and "forest vs. trees", state the same sentiment. Furthermore, we shall argue that our preoccupation with the "best" may be only an ideal that will always be unattainable or not cost effective. Real world solution to real world problem will involve compromise for the "good enough". Our research has established the distinct advantages of the softer approach of ordinal optimization for the search based type of problems, analyzed some of its general properties, and showed experimentally and theoretically in many applications orders of magnitude improvement in computational efficiency that is possible under this mind set.

## **2. COMPUTATIONALLY COMPLEX MODELING ISSUES IN COMPUTER AND COMMUNICATION SYSTEMS**

The curse of dimensionality is a major difficulty in the analysis and control strategy design of many DEDS. Examples among many are: communication networks consisting of hundreds of nodes; multiprocessor computing systems having thousands of processors; closed queuing systems with the circulating population in the hundreds or thousands; models using phase type distributions involving large or infinite dimensional Markov chains; etc. The essential difficulty to analyze these systems is that the computational

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<sup>2</sup> We hasten to add that we fully realize the distinction we make here is not absolutely black and white. A continuum of problems types exist. Similarly, there is a spectrum of the nature of optimization variables or search space ranging from continuous to integer to discrete to combinatorial to symbolic.

complexity grows rapidly with the size of the system or the dimension of the system model. They are otherwise quite tractable. In other words, the concerned performance function can be evaluated accurately when the system size is small. The situation looks so hopeless that the research effort in analytical modeling of such systems is fading away. Simulation becomes the standard approach in the research literature to justify the new designs. We solve this problem using the Newton-Pade Approximants. This approach is motivated by our earlier work on the Pade approximants applied to queueing networks and is based on the observations that performance functions of many DEDS have nice shapes as a function of the system size. They are very often provably monotonic, convex or concave, having known or easily obtainable asymptotic behavior when the system size goes to infinity. For such functions it is possible to obtain simple approximants that are virtually exact for all engineering purposes.

Experiments and theoretical analysis show that this approach provides promising tools for many applications. For example, a crucial component of control strategy in ATM network, the calculation of the cell loss probability, is currently undergoing development and the preliminary results are extremely encouraging.

### **3. Preserving the Stochastic Fidelity in Hierarchical Battle Simulation Model**

Combat simulation models usually have a distinct hierarchical structure. The high resolution level simulator generates reports which are then taken as inputs for the theater level simulator. Current practice is to use the mean values of variables from the lower level reports as the input to the higher level. This implies that significant statistical information (i.e., statistical fidelity) is lost in this process, resulting in potentially inaccurate results.

Professors Y.C. Ho and W.B. Gong's effort has been directed at developing an interface between the two simulation levels to preserve the statistical fidelity to the maximum extent that the available computing power allows. This would help greatly the U.S. Army Concept Analysis Agency in the transition from the currently used COSAGE-ATCAL-CEM simulation model to the CTLS model.

## **C. LIST OF ALL PUBLICATIONS AND TECHNICAL REPORTS**

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#### **D. LIST OF ALL PARTICIPATING SCIENTIFIC PERSONNEL SHOWING ANY ADVANCED DEGREES EARNED BY THEM WHILE EMPLOYED ON THE PROJECT**

- (1) Yu-Chi Ho, PI, Division of Applied Sciences, Harvard University.
- (2) Wei-Bo Gong, Co-PI, Department of Electrical and Computer Engineering, University of Massachusetts at Amherst.
- (3) Mei Deng, will be receiving Ph.D. degree in Nov. now employed at Bell Telephone Labs.
- (4) Li-Yi Dai, received Ph.D. degree 1993 now assistant professor at Washington University, St. Louis
- (5) Cheng-Hung Chen, received Ph.D. degree in 1994 now assistant professor at U. of Penn.
- (6) W.G. Li, N. Patsis, M. Larson, E.T.W. Lau, and L.H. Lee are currently research assistant at Harvard University under partial support of the ARO contract

(7) Wengang Zhai, Research Assistant, Department of Electrical and Computer Engineering, University of Massachusetts at Amherst. Received Ph.D. Degree in May, 1995 under the partial support of this grant.

(8) Qinghua Meng, Research Assistant, Department of Electrical and Computer Engineering, University of Massachusetts. Received M.S. degree in May, 1995 under the partial support of this grant.

(9) Anlu Yan, Research Assistant, Department of Electrical and Computer Engineering, University of Massachusetts. Received M.S. degree in May, 1992 under the partial support of this grant.

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**6. BIBLIOGRAPHY NONE**

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